



Phonon-Based Detection of Coherent Neutrino Scattering

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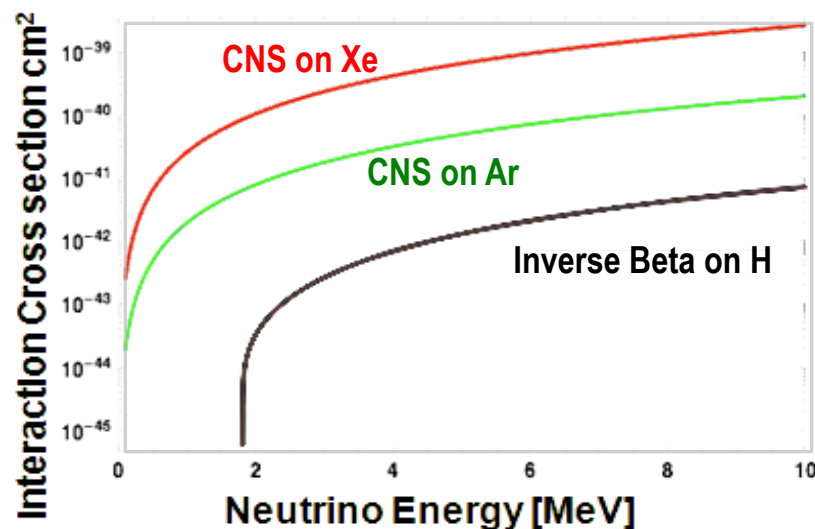
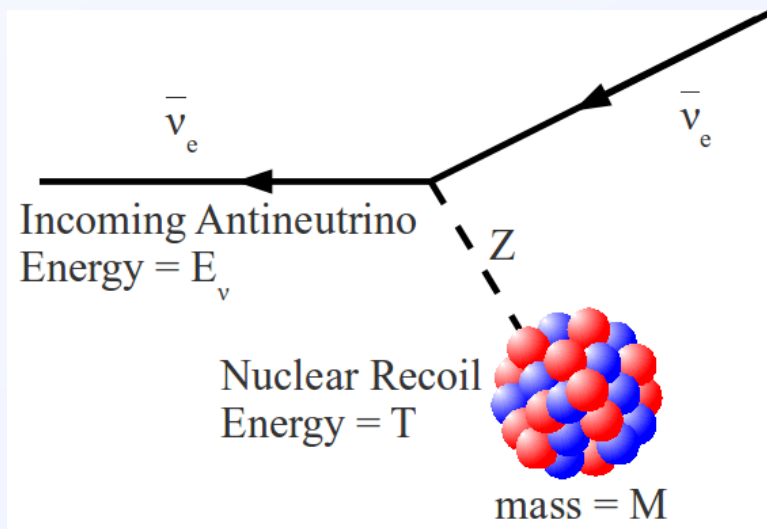




What is Coherent Neutrino Scattering (CNS)? Why is it important?

Long-standing prediction that has never been observed

100x higher cross section than other neutrino detection mechanisms



Detectors enable neutrino science...

- Neutrino oscillations
- Supernovae

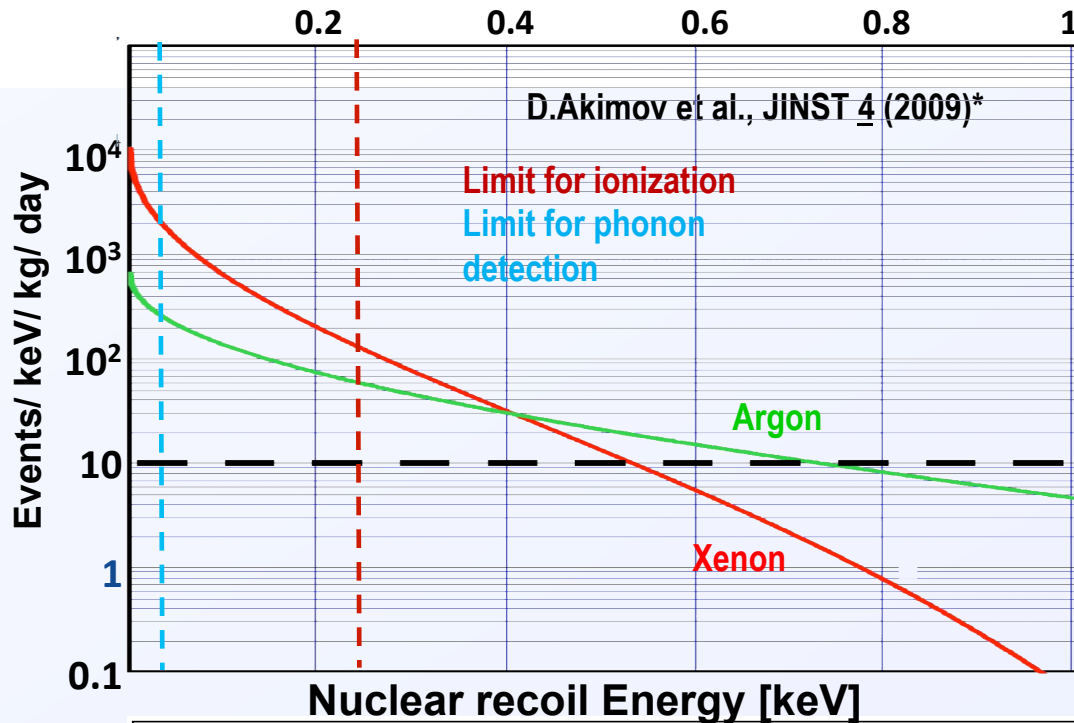
... and non-proliferation applications

- Nuclear safeguards
- Reactor monitoring





Phonon-based detection of coherent neutrino scattering

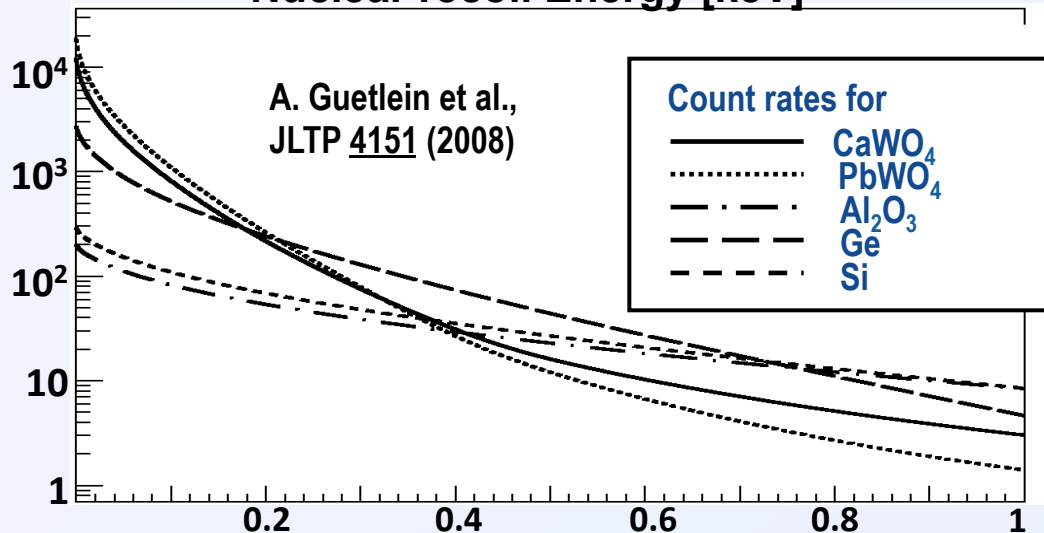


Why Phonon Based?

~100x lower detection threshold

Improvements over ionization detectors:

- 1 eV threshold
⇒ ~50x improvement in rate
- New functionality:
 - 1) Direction of recoil
 - 2) Antineutrino spectrum

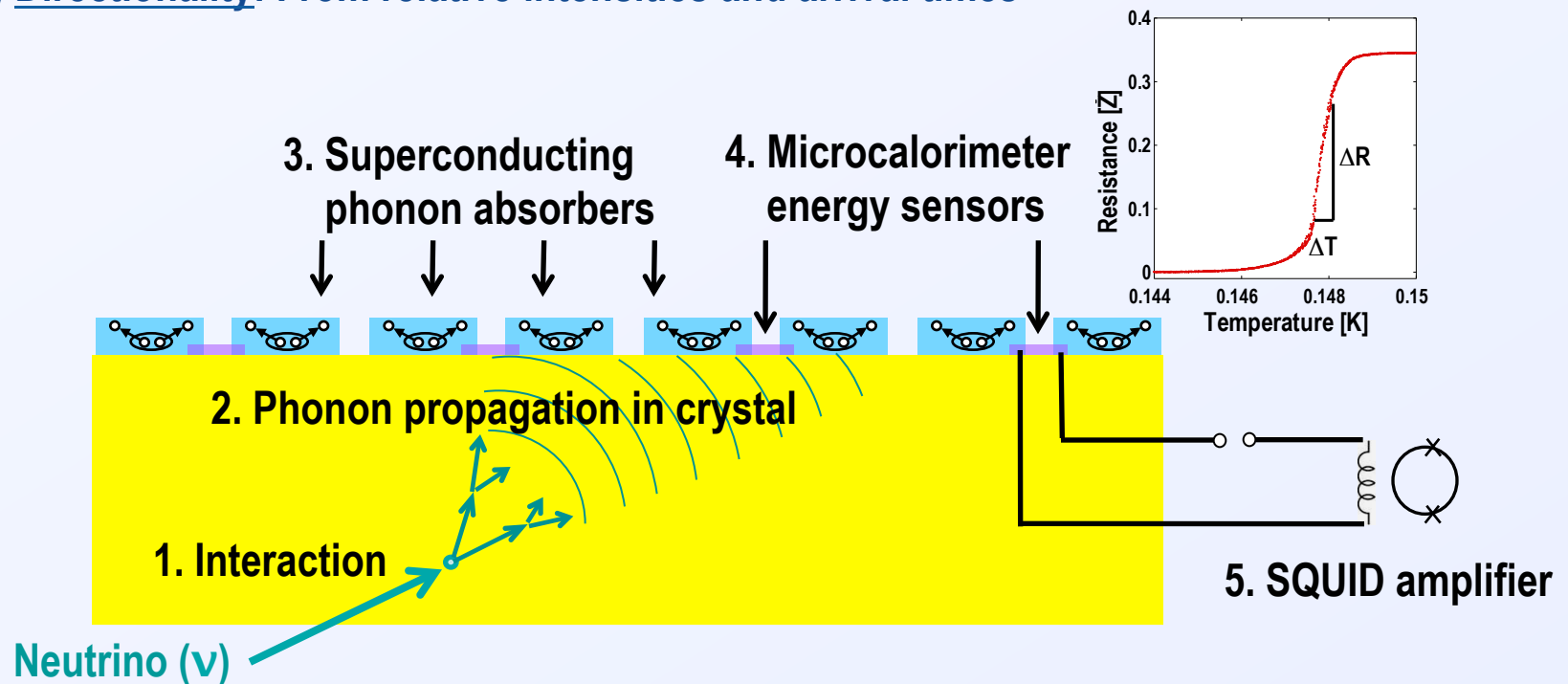




Detector Schematic

Neutrino scattering creates phonons, which are detected as a sensor resistance change

- 1) Sensitivity: Cryogenic thermal sensors have detection threshold $(k_B T^2 C)^{1/2} \approx 10 \text{ meV (!)}$
- 2) Directionality: From relative intensities and arrival times



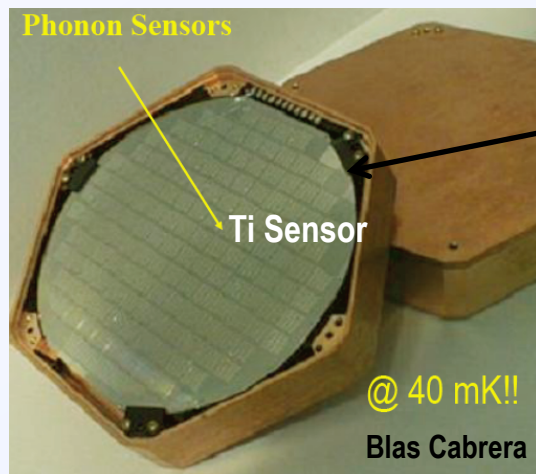
Need: 1) Ge crystal with 2) Al phonon absorber and 3) Ti microcalorimeter sensor





Technology for hot phonon detection

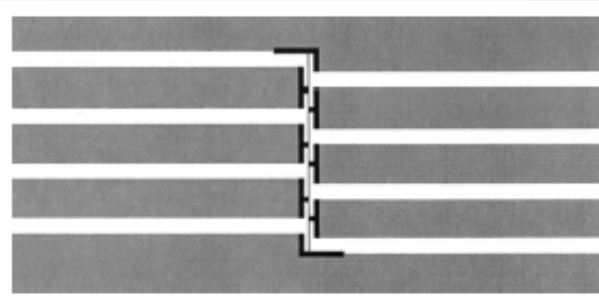
Ge crystal with absorber and microcalorimeter array (CDMS Dark Matter Search)



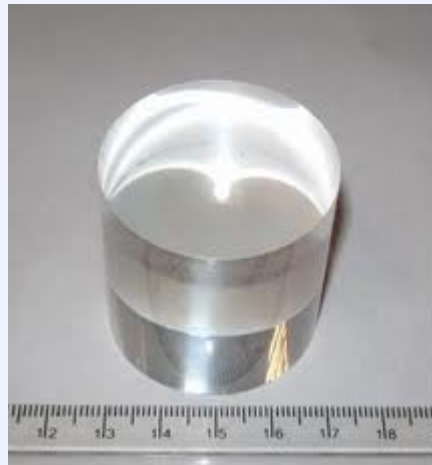
~ 1 keV detection threshold,
~25% phonon absorption efficiency
no separate pixel readout

TES micro-calorimeter with phonon-absorption fins covers the crystal surface

T. Saab et al. Nucl. Instr. and Meth. A444 (2000)



Aluminum fins are 380 by 50 μm ,
Tungsten transition edge sensor



We can use CaWO_4 or PbWO_4

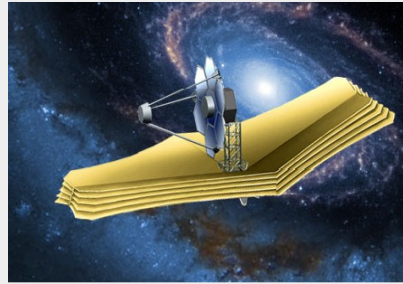
Large single crystals (1kg) available
(in use as scintillators in CRESST
dark matter experiment)

R. Lang et al. , New J. Phys. 11 :105017 (2009)

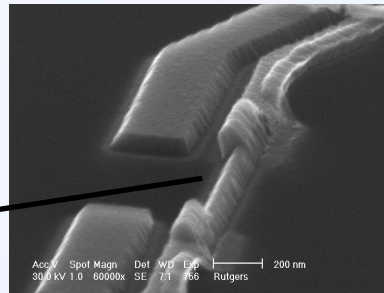
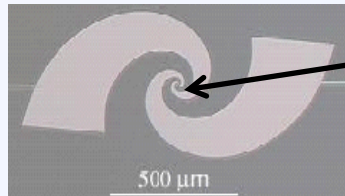




Space astronomy; Single photon detection



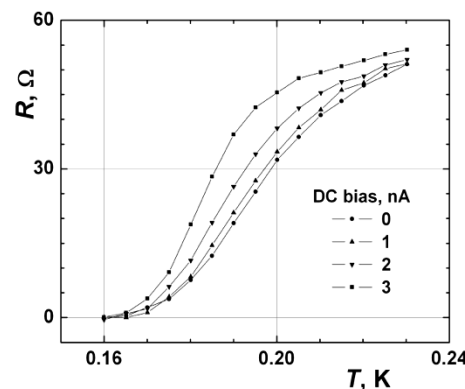
Next generation of space telescopes
with actively cooled mirrors needs single photon
sensitivity in sub-mm (THz)
SPICA (Japan), MILLIMETRON (Russia)



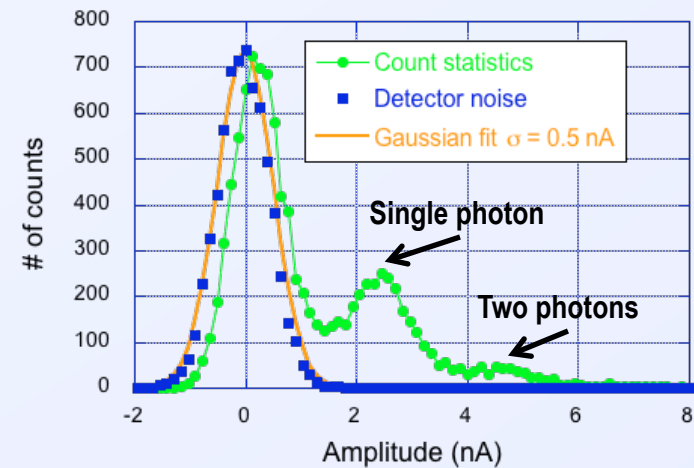
Micro-calorimeter (Rutgers, JPL)
can be referred in Astronomy as
micro-bolometer or
hot electron bolometer

$$\delta\epsilon = \sqrt{k_B T_c^2 C_e}$$

Micro-bolometer with
spiral Antenna; large focal
plane array required



Single 8μm photon detection
Temperature 30-270 mK*



S.Pereverzev, B.Karasik, ASC, Chicago 2010

* should detect sub-mm photons at low T, currently limited by parasitic readout back action





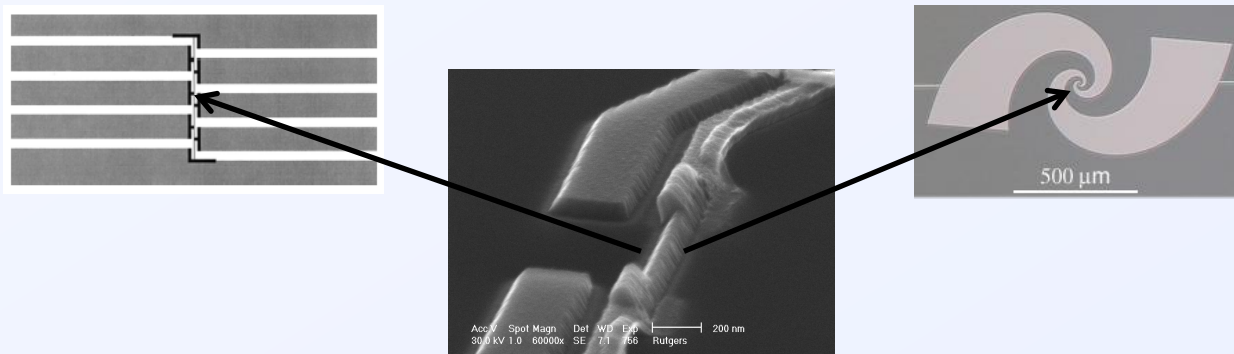
Hot phonon pulse and single photon detection comparison

CDMS	Space astronomy	phonon detector for CNS
Currently single channel, keV scale (WIMPs)	kilo- pixel, 1eV pixel sensitivity	“CNS discovery” 10-20 pixels, ~1 eV/pixel
Proposed- 10-20 pixel, detection threshold below 100eV	Goal~ below 10 meV Pixel sensitivity; Mega-pixel arrays	CNS applications-1000 pixels, 0.1 eV/pixel or better

Superconducting micro-calorimeter (*sensor) is identical for photons and phonons detection

Pixel structure is similar for photon and phonon detector

Readout of large sensitive array is common technical problem ; NB: Q-bits readout



Following general trends of sensitive superconducting technologies
Additional benefit- biochemical imaging in mid-IR





Current state: IR and MID-IR spectroscopy (mainly FTIR) for pathogen detection and abnormal tissues detection.

Clinical trials: MID-IR reflection spectroscopic devices with IR fiber probes to distinguish in vivo normal and cancer tissues. Quantitative differentiations of cancers and abnormalities.

Front-line research: detection of cancerous cells with MID-IR spectro-microscopy –bright source (synchrotron) currently required.

Revolutionizing Cell Chemical Imaging with Mid-IR photon detectors

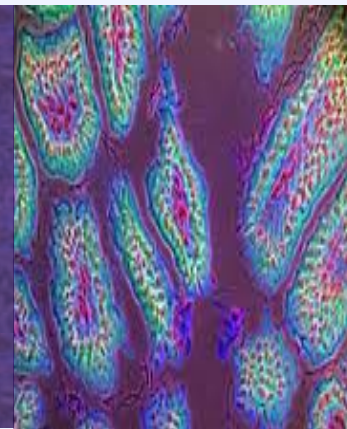
Energies of life –important processes are around 300K (30meV).

Cross-section for IR photon absorption/ resonant scattering is 10^6 - 10^{10} times larger than for Raman scattering of visible photons.

Single- molecular detection and cells differentiation possible.

Table-top set-up–semiconductor lasers instead of synchrotron .

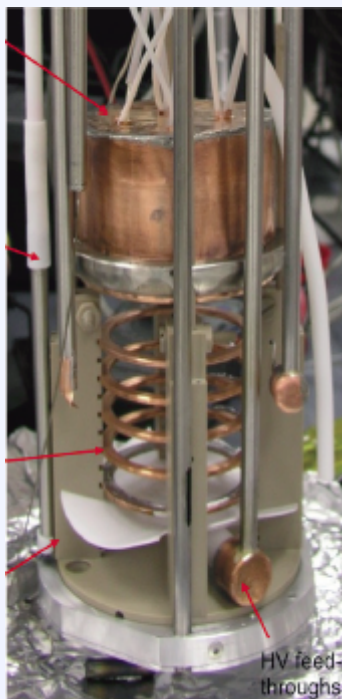
Can detect luminescence in Mid-IR.



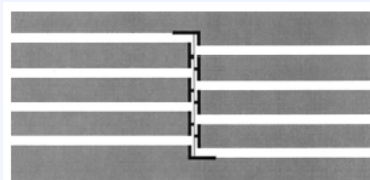
Trace organic impurity detection using resonant scattering and luminescence in Mid –IR :
get impurities frozen on quartz substrate and use cold IR spectrophotometer.



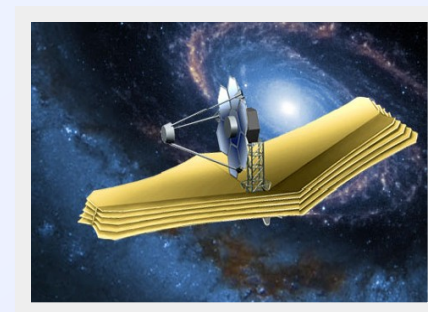
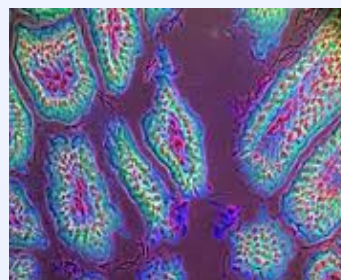
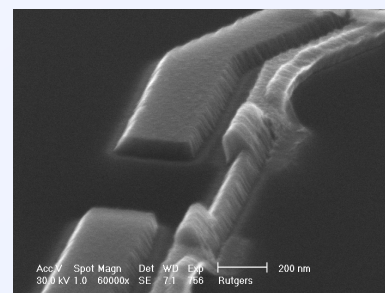
Going Infra-RED after R.E.D. ?



LLNL ionization v detector



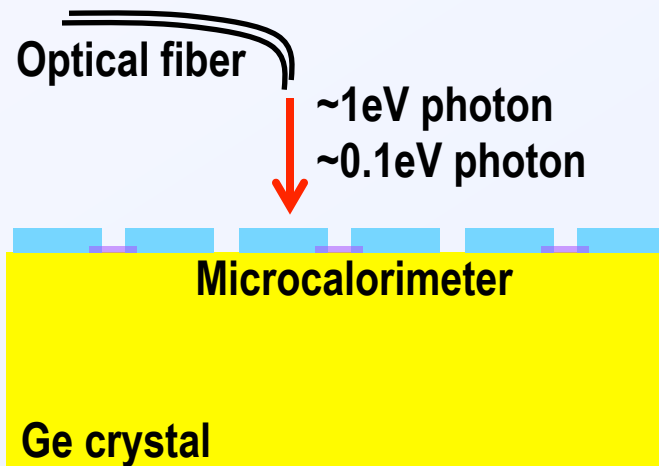
? ! ...



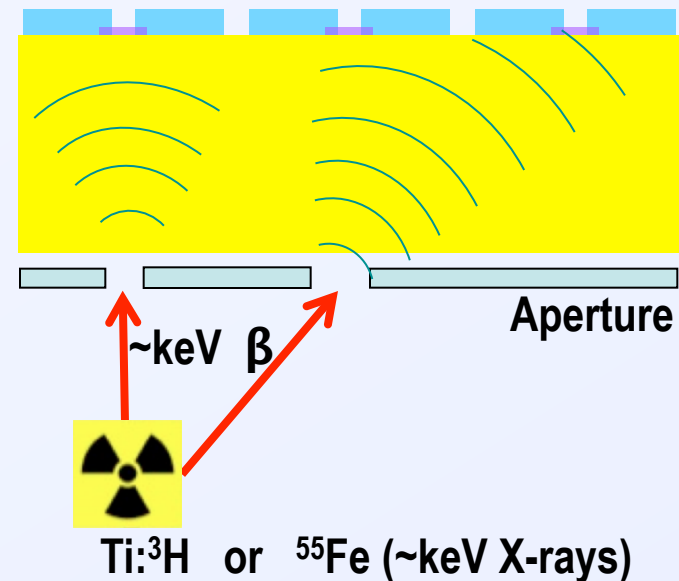


Demonstrate detector sensitivity and phonon directionality

Demonstrate $<1\text{eV}$ sensitivity
(with photons, not phonons)



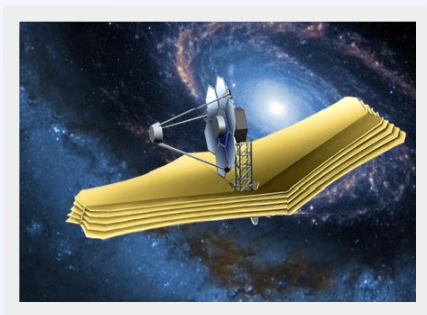
Demonstrate phonon sensitivity
(with $\sim\text{keV}$ pulses, not $\sim\text{eV}$ pulses)



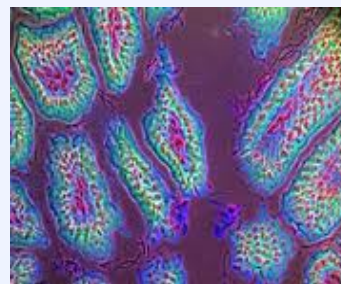
Sensitivity to $\sim 1\text{eV}$ phonon pulses with Ar ion source, directionality check

Proposal Summary and Outlook

- We want to build a hot-phonon detector to measure coherent neutrino scattering:
1) Unprecedented \sim eV sensitivity 2) Unique directionality
- Future applications for meV detectors in IR astronomy and biophysics:



e.g.
SPICA, MILLIMETRON missions



e.g.
Cell chemistry at thermal (\sim 30meV) energies

Comment

$$\delta\varepsilon = \sqrt{k_B T_c^2 C_e}$$

$$NEP = \sqrt{4k_B T_c^2 G}$$

k_B - Boltzman constant

T_c - working temperature (T_c for Ti)

G - heat conductance (from electron system)

C_e - heat capacitance (of electron system)

watch carefully while decreasing size and increasing sensitivity by 3 orders of magnitude ...